

EXPERT SYSTEM FOR TACTICAL INDICATIONS AND WARNING (I&W) ANALYSIS

Garo Kiremidjian, Albert Clarkson
ESL/TRW

Douglas Lenat
Stanford University

Adapted from ESL-Q4028

ABSTRACT

This paper addresses the problem of developing an expert system to aid the G2 intelligence analyst in performing the tactical indications of warning task. These include assimilating numerous reports based on sensor and intelligence data (in signal and symbol form); combining such knowledge with information pertaining to terrain, weather patterns, enemy organization, equipment and general capabilities; and predicting significant events in a battlefield environment such as numerical changes of enemy forces, enemy attack at key positions, unusual deployment of forces and equipment, and so forth. The specific problem areas investigated for expert systems technology applications include activation of tactical indicators; indicator relationships (how the activity of some indicators can be predicted/inferred from others); identification of information gaps and collection tasking (identifying the critical elements of information that are not available for making reliable I&W assessments, such as definitive indicator activation and how to task sensors to obtain them); and tactical warning. The approach suggested by the current work consists of incorporating expert knowledge into condition/action rules and developing appropriate frame structures for various categories of sensor and intelligence reports. A global two-dimensional data structure is used to accommodate specific reports from very different sources, efficiently trigger relevant rules, and keep the human analyst abreast of the developing threat situation. Each rule is also represented as a frame, facilitating browsing through the rules, adding new rules, and assigning credit and blame to rules. Such representation is currently a very useful feature in the development of a strategic I&W prototype expert system.

INTRODUCTION

The application of expert systems techniques to the problem of tactical battlefield indications and warning (I and W) appears extremely promising. Discussion with U.S. Army commanders, line officers, and retired

officers has led to emphasis on the following requirements in developing such applications:

- Development of battlefield threat scenarios which distribute tactical indicators chronologically.

- Identification of the types and sources of intelligence reports associated with the various classes of tactical indicators.
- Acquisition of expert knowledge on tactical I and W decision and assessment criteria for the following:
 - a. Indicator activation
 - b. Indicator relationships across time
 - c. Identification of incomplete and/or unreliable report information
 - d. Collection system tasking
 - e. Tactical warning.
- Design and development of a prototype tactical I and W expert system.

BACKGROUND

Based on several years of contract work in the areas of (1) mission planning and management, and (2) strategic I and W analysis, ESL has gained substantial experience in understanding intelligence problems and developing computer-based support for intelligence analysis tasks. The relevant work includes the following:

- a. Several years of work in I and W analysis under contract to DARPA. Work has involved extended on-site research at CINCPAC/IPAC and has lead to an experimental computer-based analytical modeling and management technology.

- b. Ongoing ID projects to develop expert systems for strategic I and W analysis and interpretation of tactical battlefield communications intelligence data for the purpose of communications net reconstruction.

PROBLEM DISCUSSION

Accurate and reliable tactical knowledge about the enemy and the area of operations is vital to command decision making in a battlefield environment. Such information is the product of tactical I and W tasks performed by experienced G2 analysts. They must assimilate numerous reports based on sensor and intelligence data, and combine the reports with facts pertaining to terrain, weather patterns, enemy organization, equipment, and general combat capabilities. Significant changes or events can then be predicted. Important questions include whether the enemy will attack, defend, reinforce or withdraw, and, if so, when, where and in what strength these conditions will occur. It is also important to distinguish enemy intentions and capabilities. Do the capabilities support the indicators or is the enemy trying to conceal his true intentions?

These assessments must not only be dependable but also timely.

Thus, tactical I and W analysis has the following characteristics:

- The problem domain is complex. A diverse set of decision criteria and heuristics is required to integrate the report data from various sensors, factor in

knowledge about the enemy's tactics and modus operandi, and then assess developing threat situations accordingly.

- Experience is essential. The effective performance of I and W analytic tasks requires experience, training, and a detailed data base. The voluminous intelligence data produced by modern collection systems must be meaningfully interpreted and properly assessed in terms of rapidly changing threat environments. This is accomplished primarily by relying on the skills and knowledge of experienced trained analysts.
- Knowledge is dynamic. Assessment of enemy capabilities is based not only on past enemy actions, but also on current enemy force characteristics and the present situation. These elements are influenced by factors such as new weapon systems (which could be in various developmental stages such as R&D, production, development, and so forth), new collection systems, current and developing political and economic conditions, and so on. Such information greatly impacts the need for frequent updates and reevaluation of the knowledge base required for the I and W analytic tasks.

These and other complexities of tactical warning mandate the application of expert systems technology. Expert systems will increase productivity and efficiency in performing timely I and W analytic tasks. Expert systems will also improve I and W training in order to overcome the scarcity of I and W

expertise and the high turnover rate of I and W analysts. The following sections describe some of the necessary steps for such applications.

INDICATORS AND THREAT SCENARIOS

The I and W analyst does not draw high-level conclusions about enemy intentions directly from incoming sensor and intelligence reports, any more than a physician makes a diagnosis directly from a patient's symptoms. In each case there are one or more intermediate levels of abstraction at which the expert reasons. The physician repeatedly combines several symptoms into a more general, more systematic indicator (e.g., specific temperature readings over a three day period may combine into "fever slowly increasing"). Similarly, the I and W analyst may combine many reports of specific enemy activity (e.g., attack formation of regimental and divisional troops in certain key areas) into a general conclusion (e.g., "deployment of combat elements in echelon"). Such general statements are called indicators, (i.e., classes of activities which signal an important change in the threat posture of an enemy force). An indicator becomes active when it is determined that such a change has taken place. The expert can then reason from a small set of activated indicators and go back to the original data just as a check of his conclusions. An indicator may be thought of as a way of symbolically, rather than statistically, "reducing" a huge mass of incoming data.

A time sequence of indicators (i.e., expert "Artillery well forward and massed," then "Maneuver forces in pre-assault formations," and so forth)

and a collection of threats (at various levels of generalization) spanning the same time period is called a threat scenario. The first step is to select a useful set of indicators which would generate viable threats and threat scenarios and provide the basis upon which to explore the utility of tactical I and W expert systems.

Table 1 contains a sample list of attack and defense intelligence indicators. An example of a tactical threat scenario is presented in Figure 1.

SENSOR AND INTELLIGENCE DATA ORGANIZATION

This step is essentially the initial phase of the knowledge acquisition process discussed below. Based on (1) relevant intelligence documentation, (2) existing sensor capabilities, and (3) knowledge of experienced analysts, generic report categories will be developed for each indicator that can accommodate specific information pertaining to the activity levels. Figure 2 is an example of an indicator and some of its possible associated report categories.

Each report category should be further defined in terms of additional parameters. These parameters are based on the following factors:

- Expectations about observed events
- Pertinent geographical features
- Types and reliability of sensors and intelligence sources.

This defines a format in which incoming reports will arrive. Each report will have specific values given by sen-

sor and intelligence data and by knowledge about sensor characteristics, expected events, and geographical areas. An example of a report pertaining to the Increased Engineering Operations indicator as shown in Figure 2, and belonging to the road-and-bridge repair category, is given in Table 2. For each item on this list, the name of the corresponding parameter is on the left-hand side of the colon sign and the value appears on the right-hand side. In most cases, the latter is a symbolic expression rather than an actual numeric value.

KNOWLEDGE ACQUISITION

The knowledge acquisition process is probably the most critical phase in the development of an expert system. It consists of acquiring a body of knowledge adequate for achieving an expert problem-solving performance in the specific task domain. Knowledge sources include the following:

- Published material such as textbooks, documents, and so forth about the domain and its problem-solving methods.
- Examples of problem-solving instances.
- Experts' past problem-solving experience.
- Experts' knowledge relevant to problem solving.

For complex and dynamical changing task domains such as tactical I and W analysis, the last two types of knowledge play a key role in the successful development of expert systems. Thus, in addition to information extracted from documentation on military doctrine and tactics, the development of

Table 1. Typical Intelligence Indicators

ATTACK

Attack may be indicated by--

<u>ACTIVITY</u>	<u>EXPLANATION</u>
Massing of mechanized elements, tanks, artillery, and logistical support.	Areas of secondary importance are often denuded to mass maximum strength for main effort.
Deployment of combat elements (mechanized, armor, antitank) in echelon.	Normal attack formation provides for second echelon of the regiment to be located 3-6 kilometers in rear of the first echelon on line; division second echelon 6-8 kilometers in rear of first echelon; and army second echelon 15-25 kilometers in rear of first echelon.
Forward units disposed on relatively narrow fronts.	The actual attack zone of a mechanized regiment is about 4 kilometers within an assigned frontage which varies from 5 to 8 kilometers.

DEFENSE

Defense may be indicated by--

<u>ACTIVITY</u>	<u>EXPLANATION</u>
Preparation of battalion and company defense areas.	Defense is based on stubborn defense of battalion defensive areas, and counterattacks by tank heavy forces.
Extensive preparation of field fortifications.	The enemy makes extensive use of trenches, prepared positions, and overhead cover in defensive operations.
Formation of antitank strongpoints.	Antitank strongpoints are formed along logical avenues of approach for armor. These are made up of mechanized engineer, and antitank gun units with positions strengthened by mines, ditches, and other obstacles.
Attachment of additional antitank units to frontline defensive positions.	In areas where there is a serious armored threat, the enemy will concentrate as many as 25 antitank guns for every 1,000 meters of front.

Table 1. Typical Intelligence Indicators -- Continued

<u>ACTIVITY</u>	<u>EXPLANATION</u>
Preparation of alternate artillery positions.	In normal defensive operations, three positions are prepared for each firing battery.
Employment of roving artillery.	Roving guns are part of normal defensive operations.
Large tank units located in assembly areas to the rear.	Tank units are held in assembly areas for employment in counterattack roles.
Preparation and occupation of successive defense lines.	In the defense, separate and distinct defense lines are prepared and occupied.
Presence of demolitions, contaminated areas, obstacles, and minefields.	Demolitions and minefields and other obstacles are placed to cover approaches to the position.
Deployment of mechanized units on good defensive positions.	Dominating terrain that has good fields of fire and is relatively inaccessible to tanks usually is selected for a defensive position.
Dumping ammunition and engineering supplies and equipment and fortifying buildings.	Engineering tools and equipment may be used to dig trenches and to erect obstacles.
Entrenching and erecting bands of wire.	Digging of trenches and the erection of of wire indicate preparations to hold the position.

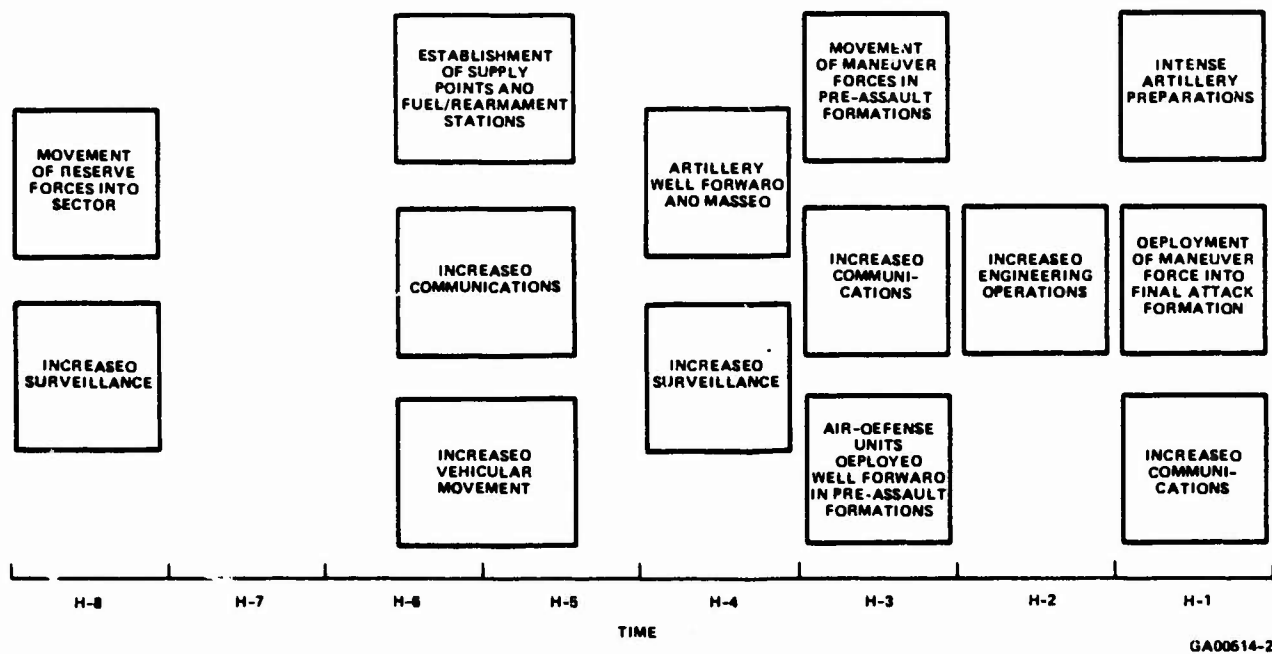


Figure 1

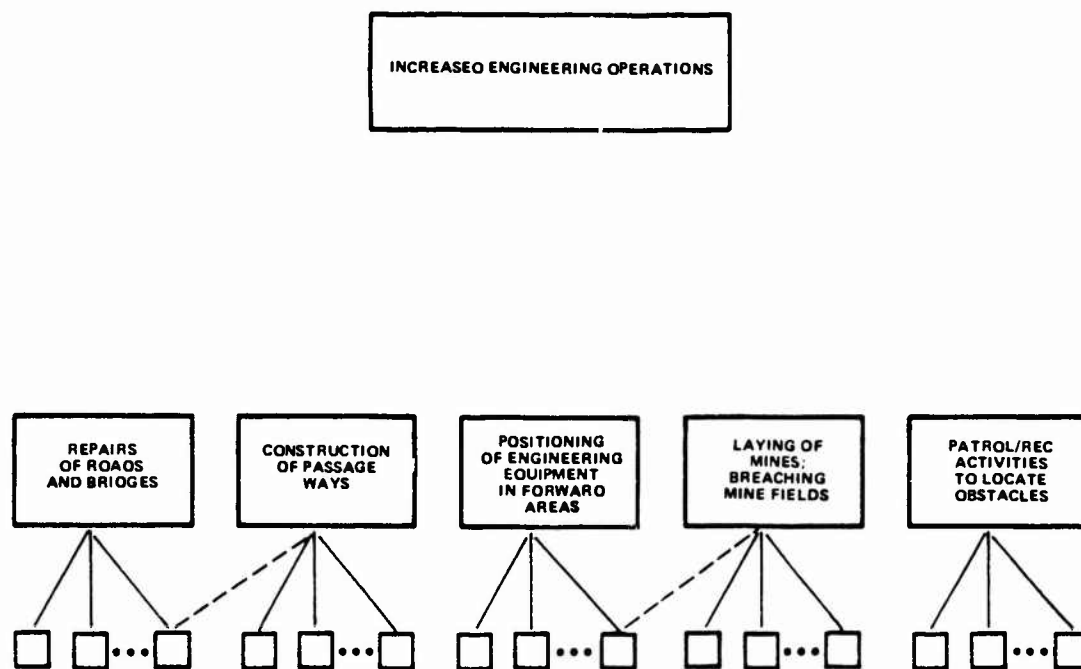


Figure 2

Table 2. Example Report

Description:	Repairs of roads and bridges.
Unit ID:	Personnel wearing engineer insignia and vehicles containing distinctive engineer corps markings and distinctive engineer equipment.
Location:	Forward areas of divisional sector DS17.
Number and Size of Equipment:	Heavy road repair machinery observed in numbers greater than those organic to the division.
Terrain:	Largely forest area with trails only.
Sensor Type:	Imagery, POW, and refugee information.
Sensor Certainty:	On a scale from 0 to 100, 80 for imagery, 50 for POW, and 30 for refugee reports.
Time:	15 June 1983, 1500 hrs.
Related Indicators:	Increased Engineering Operations.

the knowledge base of the proposed prototype tactical I and W expert system will incorporate facts, procedures, and heuristics supplied by in-house and Government-designated experts. Experts will be interviewed about how they

- Know when to activate each indicator.
- Identify vital but missing pieces of information, which would heavily affect their decisions (this drives collection tasking).
- Read patterns to conclude that certain scenarios may be in progress (this provides tactical warning).

Rules* will be developed for these analytic tasks. In general, the rules will be influenced by various factors. For example, the indicator activation criteria must be based both on the types and nature of data in specific reports and on relationships among indicators. Furthermore, the level of completeness of the specific reports and the reliability of their sources will result in rules that conclude activation with varying degrees of certainty.

* By a "rule" we do not mean a rigid constraint such as a rule of a card game. Rather, we mean a flexible guide to plausible action or decision-making, a rule of good judgement and good guessing.

In particular, knowledge about indicator relationships will be important for two reasons. First, based on current indicator activity, meaningful hypotheses could be made about verifying, expecting, and predicting threat developments in the past, present, and future. Secondly, the cover and deception aspects of incoming report data could be minimized. This means that reliable rules about activating a certain indicator should be based not only on specific reports (which could potentially reflect cover and/or deception activities) but also on the relationship of that indicator to other indicators within the context of threat scenarios.

An example of a criterion for activating an indicator called "Artillery well forward and massed" is given in Table 3. It should be noted that the last two bullets of the IF portion of the table are statements about active indicators.

The knowledge acquisition process must also address tactical I and W tasks pertaining to unconventional (nuclear) battlefield environments. Of course, significant constraint on threat assessment for such environments is the unprecedented nature. Obviously, large-scale engagements with enemy forces in critical areas of the world (such as Europe) might create novel and previously untested situations. In such cases, I and W analysis would be performed largely on the basis of expert knowledge and judgements about expected capabilities of new weapons, hypothetical enemy tactics in potentially unconventional environments, and so on. Table 4 gives an example of a criterion for activating an indicator which describes likely deployment of nuclear weapons.

Another aspect of the knowledge acquisition process will be concerned with the data input problem. The objective of this element of the proposed effort would be to acquire knowledge for the following:

- Identifying from the masses of collected data those processed sensor and intelligence systems outputs that are relevant to tactical warning (for example, information about movements of units of relatively small size or the deployment of certain types of equipment may be insignificant if considered within the warning context).
- Assigning these sensors and intelligence information components to the appropriate report categories and parameters developed as a result of the data organization effort.

The successful performance of the first task will significantly improve the efficiency of analyzing large amounts of data.

The second task will contribute to the development of capabilities for automated input of data to the tactical I and W expert system.

Finally, knowledge acquisition is an iterative process as shown in Figure 3.

PROTOTYPE SYSTEM DESIGN

ESL's approach to the prototype system design will consist of the following steps:

Table 3. Example Activation Rule

IF

Within the last two hours it has been observed that

- All organic artillery batteries in the divisional sector DS7 are in place.
- They are complemented by several non-organic batteries.
- These batteries are within 1/3 or less of their maximum range behind the FLOT and in close lateral proximity to several potential key friendly targets.
- The above information is generated from an imagery sensor of highly reliability, and the sensor timeliness factor is less than 30 minutes.
- There is an increase in artillery-related communications in DS7.
- An increase of logistic build-up in DS7 has been detected.

THEN

Activate the indicator "Artillery is well forward and massed" with high probability.

Knowledge Representation

In the field of artificial intelligence, a representation of knowledge is a combination of data structures and interpretative procedures (i.e., scheme for symbolically describing part of the world). If appropriately used in a program, these structures and procedures can lead to a knowledgeable behavior. Research on knowledge representation in AI has involved the design of several types of structures for strong information in computer programs and the construction of procedures to manipulate these structures for the purpose of making inferences.

A representation method that has been used in most of the successfully developed expert systems is based on the idea of representing knowledge in the form of rules or productions. A rule is

simply a condition-action pair. IF this condition holds, THEN take this action. In Table 3, the example of an indicator activation criterion is already expressed in the form of a rule. The IF part contains the conditions or premises and the THEN part is the conclusion or action. If the conditions are satisfied, then the rule can fire, that is, its conclusion is executed by the program. The rules examine a data structure, called the context, which means to represent the current state of the world and check to see if their IF parts are true in that state, in which case the THEN parts can fire. In an I and W expert system, the context will be comprised of incoming specific sensor and intelligence reports, order of battle, geographic and military tactics knowledge reflected in the conditions of the rules and conclusions of rules that have

Table 4. Example Activation Rule

IF

In the divisional sector it has been observed within the last six hours that

- Units are dispersing.
- Troops are digging in, hasty locations are being fortified.
- There is an increase in medical units, transports, and so on.
- Special decontamination equipment is observed in enemy area.
- Enemy soldiers are observed carrying nuclear, biological, and chemical (NBC) protective equipment.
- Chemical/nuclear ammunition/delivery means are observed.
- There is an increase or notable existence of special, secure communications traffic.
- There is an increase in meteorological/target acquisition activity.
- Wind/weather conditions favor enemy use of NBC.

THEN

Activate the indicator "Enemy is likely to use NBC weapons in next 24 hours" with 50% probability if no NBC use was made sooner, otherwise the 90% probability.

Table 5. Example of a Rule for Indicator Relationships

IF

There is strong evidence that artillery is well forward and massed.

THEN

Expect increased levels of communications and engineering operations within a time period of at most two hours.

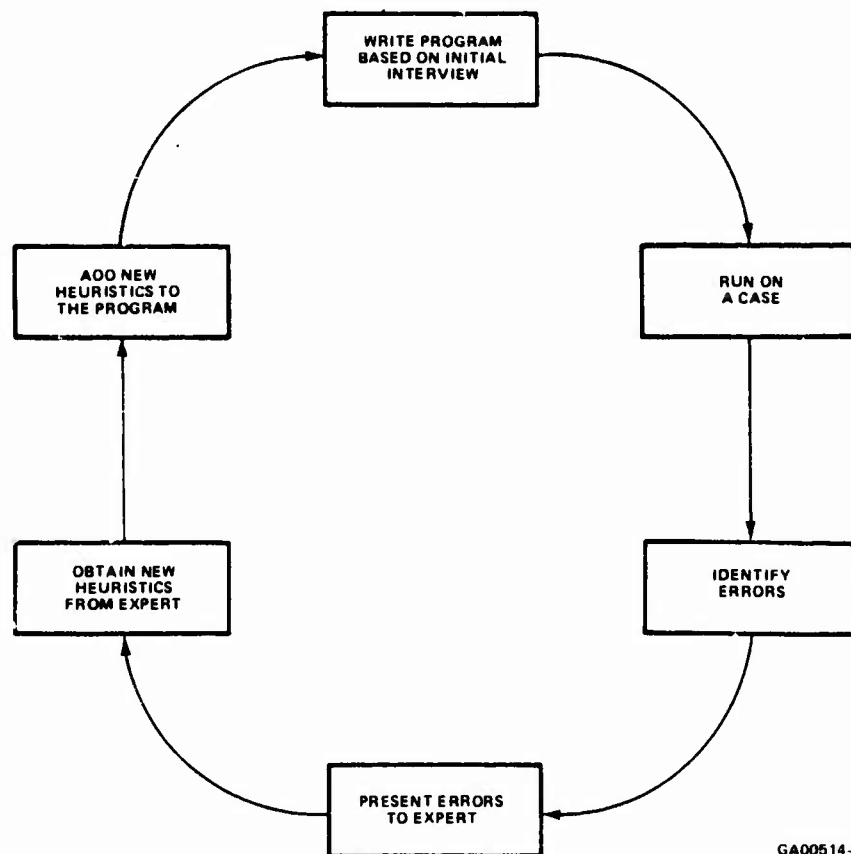
already fired. For example, the rule given in Table 5, and based on the scenario in Figure 1, has as its premise the conclusion of the rule in Table 3. The latter becomes part of the context as soon as the corresponding rule (in Table 3) has fired. Such rule changing is a convenient representation of the tactical warning process as a causal sequence of active indicators along a time line.

The above examples of rules also demonstrate another important representation feature already mentioned in the preceding section—the ability of expert systems to deal with facts and knowledge that are less than certain. Rule conclusions can be either qualified by expressions such as "likely", "highly probable", "strongly suggestive", and so on, or assigned some certainty or probabilistic numerical

factors. Both ways are acceptable to expert systems since they can perform symbolic reasoning as well as numerical computations. Furthermore, each segment of the conditional part of a rule (each expression between ANDs) can have its own certainty factor or qualifier.

Mathematical formulas or additional heuristics can combine these factors and assign a certainty value to the conclusion.

In addition to the concept of a rule, expert systems design utilizes a variety of other representation techniques. One such technique which has turned out to be particularly suitable for the development of a prototype strategic I and W analysis expert system sponsored by ESL's IR&D program is based on the idea of frames.



GA00514-1

Figure 3

Frames provide a structure within which new data are interpreted in terms of concepts acquired through previous experience. The organization of this knowledge facilitates expectation driven processing, that is, looking for things that are expected based on the current context. This type of reasoning is made possible by the use of knowledge hooks, or slots (the places where knowledge fits within the larger context created by the frame). For example, the specific report in Table 2 is already represented in the form of a frame. The slots are the report parameters. They have been created on the basis of expected observations which would characterize enemy operations on repairing roads and bridges. Furthermore, the slots are also organized in terms of requirements to support indicator activation. Thus, assessments about increased engineering operations will be made on the basis of locations of road and bridge repairs, the number and size of engineering units involved, terrain information to provide further evidence of the scope of the enemy's effort, source or sources of the reports in order to determine their credibility, and so on. The slot values are determined by sensor and intelli-

gence data and by information that may be inherited from more generic frames. For instance, the information in the unit ID slot in Table 2 may be derived from a generic report category frame because of strong expectations to observe this type of personnel and vehicles.

Data input and inheritance are only part of the available slot-filling mechanisms. The values of certain types of slots can be derived as the result of rules or heuristics operating on information provided by other slots. For instance, each specific report frame may contain a slot called "unusualness". Its value may be determined on the basis of slot information similar to the one in Table 2 and would indicate the importance of the particular report in the context of tactical warning. In AI terminology, such slot filling mechanisms are called procedural attachments.

The concept of frames is a convenient representation form not only for reports but also for indicators and even the rules themselves. An example of an indicator represented as a frame is given in Table 6. Suitable slots for a rule frame would include

Table 6. A Frame-Based Representation of an Indicator

Name:	Increased engineering operations.
Instance of:	Indicator
Reports Supporting Activity:	Road and bridge repairs, construction, equipment in forward areas, clearing mines and obstacles.
Rules for Activation:	Rule 1, Rule 2,...
Related Indicators:	Artillery well forward and massed, increased surveillance,...

IF

THEN

Indicators supported

Source of this rule

Rules that might countermand this rule.

Data Input

This phase of the design effort will investigate the development of procedures which would allow the automatic frame-based generation of reports from sensor and intelligence data. The performance of this task will utilize the following factors:

- Most of the sensor and intelligence outputs are already formatted.
- The vocabulary of the sensors and intelligence messages is based on standard military terminology and, therefore, constrained within manageable limits. Thus it will not be necessary to apply natural language understanding technology which is still too complex and in many respects, unreliable.
- Frame-based structures provide a natural environment for representing sensor and intelligence data.
- The knowledge acquisition effort will strongly emphasize the development of simple heuristics which could provide mechanisms for initial data screening. For example, expert judgment rules could eliminate a number of data items based on time, location, and subjects that are likely to be covered by these items.

User Interaction

The prototype expert system will provide the basis for the development of a computer-based system for training of I and W analysts. Thus, user interaction considerations will play an important role in the design efforts. The design phase will address the development of the following user interaction capabilities.

Explanation Facility

The representation and control structure techniques, together with the tools provided by symbolic manipulation programming environments, facilitate the development of capabilities for easy access to the line of reasoning for any inference made by the system.

Modification, Change, and Addition of Knowledge

One important feature of expert systems is its modularity. Rules behave like independent pieces of knowledge. They can be added, deleted, or changed without affecting the rest of the rules, since rules communicate only by means of the context data structure and do not call each other directly. Such capabilities can substantially enhance I and W analysis training. The user can perform simulations, access the effects of changing indicator activation rules on decisions about expected threat developments and tactical warning, and so forth.

The design efforts will also identify an appropriate rule syntax which would facilitate the user's access to the program. Furthermore, the system will be designed in such a way that user-supplied changes, modifications, and additions of rules for the purposes of

tests and simulations do not permanently affect the system's knowledge base. The latter should be altered in a significant way only by experts during periodic system maintenance reviews.

Graphics

Appropriate graphics capabilities will be developed for a meaningful display of data and inferences performed by the system.

IMPLEMENTATION AND TESTING

The system implementation will be performed on ESL's Xerox-1100 Scientific Processor, within the INTERLISP-D programming environment, which has a number of special capabilities for implementing expert systems and a variety of display and graphics functions.

The system will be developed in an incremental and iterative fashion through frequent tests and refinements. For example, during the knowledge acquisition phase experts are unlikely to present all of the relevant facts and relationships for expert performance in the domain of tactical I and W analysis. Many pertinent details about domain knowledge may be supplied by the experts in the course of their examination and critique of the performance of various system modules. These procedures would also result in refining and augmenting such system capabilities as explanation, display, user interaction, and so on.

CONCLUSIONS

This paper has presented an expert systems approach to aid tactical I and W analysts in the performance of such tasks as indicator activation, information requirements collection tasking, and tactical warning. The main knowledge engineering ideas are based on our ongoing work on strategic I and W expert system development.

ACKNOWLEDGEMENT

We are greatly indebted to Mr. Eric Vieler from ESL, Incorporated, for providing his expertise as a former Army Intelligence Officer.